New records and review of the translocation of the yabby *Cherax destructor* into eastern drainages of New South Wales, Australia

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ABSTRACT

The blue claw yabby *Cherax destructor* is a native of the Murray Darling drainage basin in the interior of south-eastern Australia. In New South Wales (NSW) the species naturally occurs west of the Great Dividing Range but recently, it has become established in eastern parts of NSW, outside of its natural range. The potential threats and translocation of this species into eastern NSW was first documented at 20 sites by Coughran et al. (2009). This paper builds on their initial work and documents a further 52 translocation sites (Table 1) recorded over the last four years. In an effort to further our understanding of the threat, we present information on the dispersal of this species together with observational information on interactions with freshwater crayfish (Parastacidae) species and suggest recommendations to help slow the translocation process.

Key words: crayfish, *Cherax destructor, Euastacus dharawalus, Euastacus hirsutus, Euastacus reductus, Euastacus spinifer, Gramastacus* sp., invasive crayfish, translocation, threatening process, yabby.

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Introduction

The Murray Darling basin covers one seventh of the Australian continent, draining an area of over one million square kilometres. It includes 20 major rivers including the three longest rivers in Australia; the Darling, Murray and Murrumbidgee. The blue claw yabby *Cherax destructor* is endemic to all these drainages, being widespread in central and south-eastern Australia (Riek 1969; Sokol 1988). It is a robust species with the ability to tolerate extreme physicochemical conditions (Beatty *et al*. 2005) and their wide distribution reflects an ability to thrive in a wide range of habitats from permanent to semi permanent water bodies (McCormack 2008).

This broad range of environmental tolerance, plus its capacity for very rapid growth and maturity at a small size and young age (Wingfield 2001) makes the species ideal for culture. *Cherax destructor* is currently commercially grown by 72 licenced commercial farmers in NSW (NSW DPI 2012a). The cultured yabbies are sold alive for a range of purposes including: food for human consumption; food for native animals (e.g. in zoos, reptile parks); feeder yabbies for aquarium species; pets for aquariums; research stock of schools and Universities; bait for recreational fishermen and dam stock to seed farm dams as a home grown food source (McCormack 2005). This broad spectrum of uses for live yabbies creates multiple potential pathways for translocation into the wild. Potential translocation pathways may include; escape of live bait, release of unused live bait, deliberate release of unwanted aquarium pets, plus escape of the species from dams or flooded household aquariums during flood events. All these factors, plus the deliberate illegal stocking of the species to the wild, have seen an increase of the species distribution in the eastern drainages of NSW.

Freshwater crayfish surveys of eastern NSW were undertaken as part of the Australian Crayfish Project (ACP) and targeted sub-projects of specific regions. The ACP is surveying the whole of eastern Australia from Pajinka, Cape York, the northernmost point, to Wilsons Promontory, Victoria, the southernmost point of mainland Australia. The ACP records the freshwater crayfish species present at thousands of survey sites to provide baseline data of the species present in a particular section of stream at a set point of time. In this paper we document the ACP records of *C. destructor* translocations in NSW and record our observations of interactions with the aim to further our understanding of the threat to eastern endemic crayfish.

Figure 1. The blue claw yabby *Cherax destructor.*

Methods

Crayfish were collected using a variety of methods to suit the conditions at each survey site. Opera house traps (630 mm x 470 mm x 180 mm, 90 mm steel ring entrance hole) and box traps (430 mm x 260 mm x 260 mm, 40 mm steel ring entrance hole) were used; all baited with fresh fish and set for 2-24 hours. Scoop rakes and scoop nets were used for 5-10 minutes to sample suitable sites. Many sites were hand sampled for 10-30 minutes, included lifting structures like rocks and logs and excavating burrows, using hands and with the assistance of spades. Burrows were carefully and slowly excavated so that the burrow and any branches could be followed. Careful burrow excavation also provides information on the species habitat requirements and burrow system structures.

Voucher material was retained where appropriate (representative of that species at that site at that time) and all retained specimens were placed in transport containers with a small amount of water and returned live to the laboratory. Specimens were photographed and examined in the laboratory under dissection microscopes, measured with digital callipers and then weighed to 0.1 of a gram. Specimens were euthanized by freezing for at least 24 hours and subsequently stored in clear, labelled specimen jars containing originally 70 % ethanol (and now 100 % ethanol to better retain genetic integrity for our genetics programs with James Cook University and the Australian Museum). Additionally tissue samples from live animals were retained in cell lysis buffer from selected specimens for subsequent DNA analysis, as part of the broader ACP via our Carnegie Museum of Natural History genetics program.

Voucher specimens are collected and lodged into the ACP collection; from there selected specimens are lodged into the collections of: The Australian Museum, The Carnegie Museum of Natural History, The James Cook University Collection, The Museum Victoria, The Queensland Museum. Additionally, results of all the surveys are included in the Atlas of NSW Wildlife database and the Queensland government's (WildNet).

At each site, the co-ordinates and altitude were recorded using a Magellan Explorist 510 and 600 handheld GPS. Notes were taken on exact locational details, landforms, aquatic vegetation and stream conditions. Water quality information (flow, pH, temperature, salinity, visibility, DO, conductivity and TDS) is also recorded at selected sites.

Occipital carapace length (OCL) is the standard measure of size for freshwater crayfish. The OCL extends obliquely from the eye socket to the dorsal posterior of the carapace.

Results

Cherax destructor was documented at 20 sites in eastern drainages (Table 1, Figure 2) by Coughran *et al.* (2009). Between March 2009 and March 2013, another 1330 sites in eastern drainages of NSW were surveyed as part of the ACP. Approximately, 40 % of these sites contained endemic crayfish species, with many of those sites containing two or more native species. The yabby *C. destructor* is an adaptive species and the results of our surveys recorded 52 additional sites where the species is now established (Table 1; Figure 2). We located *C. destructor* in eastern drainages from close to the coast at 7 m a.s.l to the start of the catchment along the top of the Great Dividing Range at 1240 m a.s.l.

Additionally, NSW Department of Primary Industries (NSWDPI), Fisheries NSW conducts aquatic biological surveys of NSW. The Fisheries NSW Parastacidae collection was also examined and four sites containing *C. destructor* were also recorded.

Discussion

Eastern NSW has three genera of native freshwater crayfish. Compared to *C. destructor*, *Euastacus* have restricted distributions and slow growing that take years to attain maturity (Morgan 1997; Gilligan *et al.* 2007; McCormack 2008). *Cherax* and *Gramastacus* both have small restricted distributions with specific habitat requirements (Coughran 2005; McCormack *et al.* 2011; McCormack *et al.* in prep; McCormack 2013a in press).

The impacts of translocated populations of *C. destructor* in other areas of Australia have been discussed by Austin (1985); Bradsell *et al.* (2002); Elvey *et al.* (1996); Horwitz (1990); Horwitz and Knott (1995); Merrick (1995) and Beatty *et al.* (2005), and these impacts would also be relevant to eastern NSW. Additionally, Coughran *et al.*

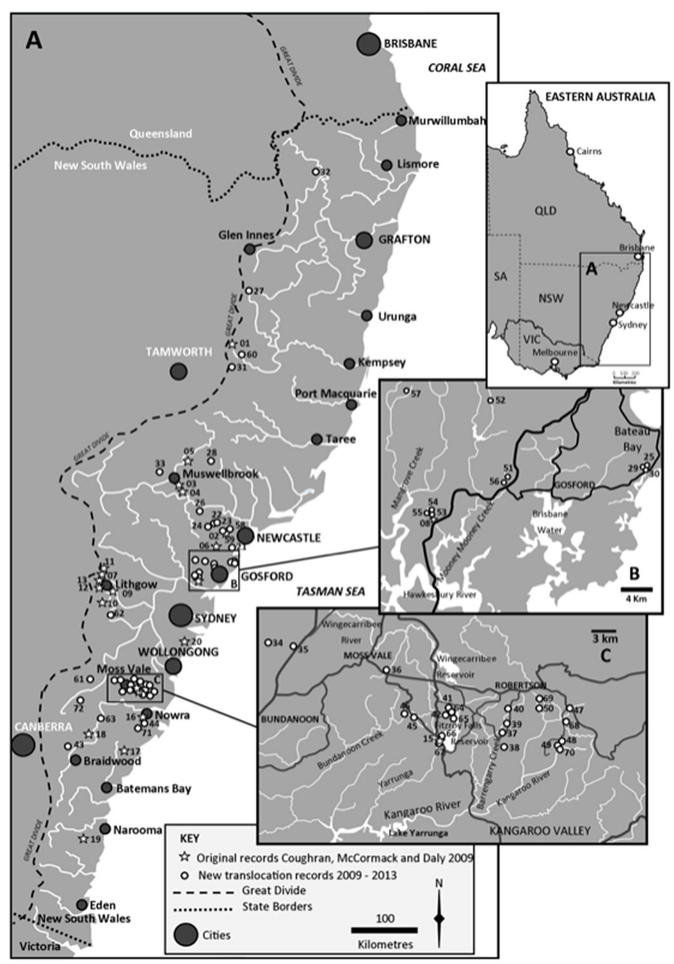

Figure 2. Records of translocation of the blue claw yabby, *Cherax destructor*, in coastal drainages of eastern New South Wales.

Table 1. Locality details for the records of established populations of translocated yabbies, Cherax destructor, in eastern New South Wales. * registration code of voucher material retained (where applicable), as part of the Australian Crayfish Project or NSW DPI Fisheries data base

Site No.	Date of Capture	Latitude	Longitude	Site Details	Catchment	Altitude (m)	ACP Voucher Codes*
Original records of translocation (Coughran McCormack and Daly 2009)							
	27/12/2007	30.8223	151.5437	Frizzy Ck, Uralla Rd crossing, north of Walcha	Macleay	1000	952-957
	27/12/2008	32.9209	151.5159	Forest dam, Heaton SF, near Mount Sugarloaf	Lake Macquarie	400	1646-1649
	10/01/2005	32.3441	150.9514	Un-named creek into Lake Liddell, Singleton	Hunter	150	n/a
	10/10/2005	32.3542	150.9895	Lake Liddel, Singleton	Hunter	145	n/a
	5/07/2007	32.1043	151.0147	Lake Glenbawn, eastern shores	Hunter	300	n/a
	28/11/2008	32.9936	151.4456	Dam side road, Heaton Lookout Rd & Watagan Rd, Watagan Mountains	Hunter	520	1588-1590
	19/04/2008	33.3948	150.0784	Wangcol Ck, Brays Lane crossing, Lithgow	Hawkesbury	890	1144-1145
	6/12/2008	33.4554	151.1943	Calvetts Ck, old Pacific Hwy crossing, Mount White	Hawkesbury	170	1642-1644
	11/02/2009	33.5413	150.1673	Boxes Ck, Blackmans Ck Rd crossing, Hartley	Hawkesbury	725	1849-1853
	11/02/2009	33.6521	150.0899	Gangenang Ck, Marsden Swamp Rd crossing	Hawkesbury	690	1856-1857
	11/02/2009	33.5499	150.1242	Coxs River, McKanes Fall Rd crossing (under McKanes Bridge)	Hawkesbury	730	1866-1867
	11/02/2009	33.5241	150.0782	Lake Lyell, at launching ramp, Lithgow	Hawkesbury	790	1868-1869
	21/02/2009	33.4140	150.0744	Lake Wallace, at lake shore end road in park, near Wallerawang	Hawkesbury	880	1877-1879
	5/03/2007	34.6446	150.4830	Wildes Meadow Ck, last picnic area above Fitzroy Falls, Morton NP	Shoalhaven	700	642-643, 647
	26/09/2006	34.6451	150.4840	Wildes Meadow Creek, above Fitzroy Falls, Morton NP	Shoalhaven	700	411, 444
	9/09/2008	34.9667	150.6000	Parma Creek, above falls, south of Nowra	Clyde	20	n/a
	2007	35.3667	150.3500	Farm dam, Jindalara Creek Road, west of Ulladulla	Clyde	70	n/a
	5/03/2007	35.1667	149.9917	Grassy Ck, Oatley Road crossing, edge of Morton NP	Shoalhaven	550	633-636
	2/06/2007	36.2639	149.9563	Reedy Ck, Tin Pot Rd, Bodalla SF	Tuross	250	772
	19/02/2008	34.2333	150.8445	Stokes Ck, Dharawal SCA	Georges	350	n/a
New records of occurrence 2009 - 2013							
	23/8/2009	33.17092	151.53610	Tyre track holes beside Ruttleys Rd, Mannering Park	Lake Macquarie	45	2296/97/98
	19/9/2009	32.80751	151.34388	Creek xing Pinchen St, Nulkaba	Hunter	83	2404
	14/9/2009	32.81020	151.34347	Creek beside Pinchen S & crn O'Connor St, Nulkaba	Hunter	88	2405
	14/9/2009	32.81198	151.31299	Creek xing Oakey Road, Pokolbin	Hunter	95	2407
	25/9/2009	33.40966	151.46021	Swampy area south side of Bakali Rd, Bateau Bay	Wamberal Lagoon	12	2428/29/30
	29/9/2009	32.61691	151.18639	Small crk/drain xing Range Road, Whittingham	Hunter	70	2437/38/39
	17/3/2010	30.20689	151.71701	Crk xing Wards Mistake Rd, Guyra	Macleay	1240	2769/70/71
	24/4/2010	32.21729	151.26387	Trib of Fal Brook xing Cassells Rd	Hunter	598	2845/46
	26/5/2010	33.40955	151.45955	Wetland west of Bakali Rd	Wamberal Lagoon	10	2930
	10/6/2010	33.40927	151.45890	Wetland west of Bakali Rd	Wamberal Lagoon	7	2982/85
	10/7/2010	31.04503	151.58276	Trib Apsley River xing Thunderbolts Way, Walcha	Macleay	1091	3022
	10/7/2010	28.89516	152.49004	Little Yellow Creek, xing Bruxner Hwy, Drake	Clarence	169	3030/31/32
	2/10/2010	32.19060	150.76760	Unnamed watercourse, tributary Sandy Creek, Hanging Rock	Hunter	294	3426/27

17/2/2011	34.52656	150.24110	Forestry dam and crk in Belanglo State Forest	Hawkesbury	704	3566
17/2/2011	34.53468	150.28075	Roadside pond near Wells crk Rest area Hume Hwy	Hawkesbury	639	3567
28/4/2011	34.56464	150.40769	Trib Kelly Crk, xing Illawarra Hwy, Moss Vale	Hawkesbury	673	3623
28/4/2011	34.63995	150.56879	Trib of Barrengerry Crk xing Belmore Falls Rd, Burrawang	Shoalhaven	644	3631/32/33
28/4/2011	34.65256	150.57301	Road side drain beside road, trib of Barrengarry Crk	Shoalhaven	639	3635
28/4/2011	34.63013	150.58013	Trib of Barrengarry Crk xing Belmore Falls Rd, Burrawang	Shoalhaven	663	3638
28/4/2011	34.60944	150.58378	Barrengarry Crk xing Belmore Falls Rd, Burrawang	Shoalhaven	629	3639
28/4/2011	34.61028	150.49905	Crk xing Cleary Lane, Wildes Meadow	Shoalhaven	687	3643/44
28/4/2011	34.61466	150.48998	Creek xing Bresnahan Lane, Wildes Meadow	Shoalhaven	697	3645
2/9/2011	35.30180	149.71042	Creek xing King Hwy, Manar NSW	Shoalhaven	617	3792
2/9/2011	34.97936	150.58793	Crn Old Princes Hwy & Dowling St, Falls Creek	Jervis Bay	31	3793/94
26/10/2011	34.61240	150.44218	Tributary Bundanoon Creek, beside Nowra Road, Manchester Square	Shoalhaven	655	3826
26/10/2011	34.61082	150.44085	Bundanoon Creek, beside Nowra Road, Manchester Square	Shoalhaven	652	3827
3/11/2011	34.61073	150.66705	Kangaroo Creek xing Jamberoo Mountain Road	Shoalhaven	582	3832
3/11/2011	34.65750	150.65423	Gerringong Creek off a private road at the end of Cloony Road then through grazing paddock then walk to creek.	Shoalhaven	554	3834/35/36
3/11/2011	34.65535	150.65220	Unnamed watercourse off a private road at the end of Cloony Road then through grazing paddock then walk to creek.	Shoalhaven	556	3837/38
3/11/2011	34.61180	150.62385	Dharawal Creek below Fountaindale Road	Shoalhaven	558	3841
29/2/2012	33.41368	151.28928	Trib of Piles Creek, at corner of Somersby Falls Road and Wisemans Ferry Rd	Hawkesbury	180	3938
29/2/2012	33.33503	151.26864	Little Mooney Mooney Ck crossing Little Mooney Mooney Rd, Somersby	Hawkesbury	244	3943
1/3/2012	33.45263	151.19449	Trib Calvert Crk xing Ashbrookes Rd, Mount White	Hawkesbury	178	3944
1/3/2012	33.45017	151.19246	Trib Calvert Crk xing Ashbrookes Rd, Mount White	Hawkesbury	186	3945
1/3/2012	33.44937	151.19165	Trib Calvert Crk xing Ashbrookes Rd, Mount White	Hawkesbury	184	3946
13/3/2012	33.41920	151.28632	Piles Creek crossing Pacific Hwy, Somersby	Hawkesbury	170	3952/53
31/3/2012	33.32428	151.16765	Crafts Creek xing Maroney Rd, Mangrove Mountain	Hawkesbury	265	3969/70/71
17/7/2012	32.96728	151.46306	Forest dam, Heaton Road, Heaton State Forest	Hunter	491	4081/82/83
17/7/2012	32.99366	151.44551	Forest dam, Heaton Road & Mount Faulk Rd, Watagans National Park	Hunter	483	4084
4/11/2009	31.04990	151.76650	Apsley Falls, Apsley River	Macleay	1009	DPI-13
8/11/2010	34.50181	149.98727	Junction Crk, Near Brayton Rd	Hawkesbury	595	DPI-120
14/11/2010	33.73101	150.23598	Megalong Ck, near Megolong Valley Rd	Hawkesbury	553	DPI-121
15/11/2011	35.13975	150.06964	Nadgengutta Ck	Shoalhaven	574	DPI-135
28/4/2011	34.61028	150.49905	Unnamed water course draining towards the reservoir	Shoalhaven	695	Dharawalus survey
26/10/2011	34.62465	150.50733	Eastern bank of Wildes Meadow Channel, Fitzroy Falls Reservoir.	Shoalhaven	671	Dharawalus survey
26/10/2011	34.63993	150.48439	Western shore of the Fitzroy Falls Reservoir	Shoalhaven	660	Dharawalus survey
26/10/2011	34.64520	150.48330	Wildes Meadow Crk, below reservoir	Shoalhaven	655	Dharawalus survey
3/11/2011	34.63223	150.66185	Old Saw Mill, below Cloonty Road Kangaroo River	Shoalhaven	570	Dharawalus survey
3/11/2011	34.61179	150.62385	Dharawal Creek below Fountaindale Road	Shoalhaven	589	Dharawalus survey
3/11/2011	34.65752	150.65977	Gerringong Creek off a private road at the end of Cloonty Road	Shoalhaven	556	Dharawalus survey
4/10/2012	35.03527	150.49186	Flat Rock Creek, xing Turpentine Rd, Yerriyong State Forest	Jervis Bay	187	4141
4/2/2013	35.73611	149.83064	Towrang Creek at rest area, Hume Hwy Murrays Flat	Hawkesbury	638	4329/31

(2009) discussed some of the ramifications of *C. destructor* expanding into the eastern drainages of NSW.

Many characteristics give *C. destructor* the potential to out-compete less competitive endemic freshwater crayfish species and adversely affect the eastern coastal aquatic ecosystems (Table. 3)

In addition, the amenable climate and higher rainfall of coastal areas combine to create greater availability of aquatic habitat. Coupled with rural and urban development habitat alteration in eastern drainage ecosystems, there is an extensive opportunity for a robust invasive species that prefers the cleared riparian zones, sedimented streams and impounded waterbodies to rapidly replace sensitive native species.

Cherax destructor can rapidly repopulate an area through dispersal and a relatively high reproductive rate (Rankin 2000) so small translocations of several specimens in small habitat altered areas can rapidly escalate into enormous populations. The species ability to produce two generations per year and the high fecundity of the species ensures that once translocated, the species may become established within the first 12-24 months.

Observations

Further to the suggested adverse impacts to the aquatic ecosystems of eastern NSW, first recorded by Coughran *et al*. (2009), we provide the following examples of our observations that indicate impacts to the three genera of endemic crayfish species.

Table. 2. Results of the June 2010, Wamberal area survey with 6 box traps soaking for a 24 hour period.

Cherax destructor		
Number	Sex	Weight (grams)
1.	Male	38
2.	Male	80
3.	Male	54
4.	Aberrant	50
5.	Aberrant	99
6.	Male	71
7.	Male	82
8.	Male	59
9.	Male	77
10.	Male	42
11.	Male	67
12.	Male	71
13.	Female	34
14.	Male	32
15.	Male	25
16.	Female	14
17.	Female	29
18.	Aberrant	8
19. Spec 2882	Male	101
20. Spec 2985	Male	102
Gramastacus sp.		
1. Spec 2983	Male	4
2. Cut into pieces	?	Similar to above

Example 1 - Wamberal, Wamberal Lagoon Catchment, Central Coast (predation)

Cherax destructor was first identified in the area during routine ACP surveys in 2009 (site – 25). A follow up survey in May 2010 of the Wamberal Lagoon catchment identified both *C. destructor* and *Gramastacus* sp., in a small wetland area (McCormack 2010). This is a new *Gramastacus* species only recently identified (McCormack 2013a in press). To date *Gramastacus* species have been documented in lowland (3-48 m a.s.l.) ephemeral habitats along the coast strip from Wamberal Lagoon, north to Wallis Lake. This new population discovered

Table. 3. Characteristics of *Cherax destructor*

Characteristics of *C. destructor*
They mature rapidly, less than 6 months to sexual maturity (Wingfield 2001)
They breed easily, with repetitive spawning common and females may brood up to three times per year (Rankin 2000; Wingfield 2001; McCormack 2005)
They have large numbers per brood (small ACP Spec 1665, 10 g, 24.55 mm OCL, 153 eggs) with an average of about 300 eggs being produced in a single spawning event (Rankin 2000)
They have a short gestation period of 6 - 8 weeks, with the adult females protecting the eggs until the juveniles have hatched and separated from the female (Rankin 2000; McCormack 2005)
They are primarily omnivorous and an opportunistic feeder (Rankin 2000; Purvis 2005);
They can survive out of water for long periods, as long as their gills are kept moist in humid air (Rankin 2000);
To avoid prolonged unfavourable environmental conditions, yabbies burrow down to the water table, constructing a small moist chamber where they shut down their metabolic functions and can aestivate for several years (Johnson 1981; Rankin 2000; Wingfield 2001; McCormack 2005);
Yabbies are also considered to be highly mobile, migrating upstream and overland (Rankin 2000; McCormack 2005)
They have good salt tolerance being able to tolerate salinities up to about 25 ppt (2.5%) (Rankin 2000; McCormack 2005)
They have simple habitat requirements preferring open sky conditions and turbid water. Most native eastern NSW species prefer intact riparian zones or heavily reeded habitats that shade or reduce sunlight to the habitat areas and clear water. ***Cherax destructor*** prefers the opposite, cleared riparian zones, bare banks and barren substrate with full sunlight and turbid water being their preferred habitat areas (McCormack 2008)
They are tough and can tolerate a wide range of environmental conditions such as poor water quality and differences in water temperatures as low as 1 °C and as high as 35 °C (McCormack 2005; Purvis 2005)
They are very tolerant of low oxygen levels (Morris & Callaghan 1998)
Cherax destructor can obtain a large size of 81 mm OCL and weight 350 grams (McCormack 2008).

in Wamberal Lagoon catchment represents the most southern distribution. The Wamberal distribution area consists of only two small ephemeral wetland areas less than 50 m diameter, each with low population densities. These two small remnant populations are extremely vulnerable and increasingly threatened as they occur on land under pressure from development.

Our surveys indicate *C. destructor* is widely dispersed throughout the *Gramastacus* distribution area, and appears well established. They were originally easily identified by their large burrow systems, scattered throughout the area when the wetland was dry. Another follow up survey using baited traps was conducted in early June 2010 over a 24 hour period when the wetland was flooded. Because the survey was undertaken in winter, with cool water temperatures, catch numbers were small. The results, however, are a good indication of the distribution and size of animals in residence. Only the two largest specimens were vouchered (ACP Specimen 2982 and 2985), however, another 18 crayfish were captured (Table 2). All the *C. destructor* specimens captured were mature adults, as were the two *Gramastacus* sp. captured. Of the two *Gramastacus* sp. captured in the box trap with just two *C. destructor*, one was alive (hiding in top corner of trap) while the other was killed by aggressive interactions with *C. destructor* also captured.

It has been my experience (as a commercial farmer and fisher of *C. destructor* for over 30 years) that they are an opportunistic species. Large adults have the stamina to dig a deep burrow and survive extended periods within their burrows until a rain event occurs and surface water returns. They then emerge, breed prolifically and rapidly populate a water body. The number of *C. destructor* increase dependent on the available food and shelter. I suggest that as the water recedes to smaller water bodies, available food reduces and the species cannibalizes smaller animals. Cannibalism is a constant problem with *C. destructor* (Carroll 1981) and high juvenile mortality mainly due to cannibalism limits population density (Rankin 2000). I expect a ravenous large *C. destructor* would not distinguish between a juvenile *C. destructor* and similar sized small *Gramastacus* and both would be prey.

The aggressive nature of *C. destructor* is a major concern for the smaller *Gramastacus* crayfish (Figure 3). As the water levels in these ephemeral wetlands reduce the *Gramastacus* will be forced into closer interactions with the larger *Cherax* finding it increasingly difficult to avoid them. I suggest that this outbreak of *C. destructor* is an ongoing significant threat to this population of native *Gramastacus*.

Figure 3. Both mature adults captured together Wamberal, NSW. Top: Translocated *Cherax destructor* 102 grams, 56.44 mm OCL. Bottom: *Endemic Gramastacus* sp., 4 gram, 17.36 mm OCL.

Example 2 - Mount White, Hawkesbury River Catchment (displacement)

Cherax destructor was first documented in Calverts Creek (Tributary Mooney Mooney Creek - site 08) at Mt White in 2008 as part of the ACP general surveys. At that time a 50 m section of the main creek was surveyed, both *Euastacus australasiensis* and *C. destructor* were in good numbers and captured together. Surprisingly, a follow up survey of the same 50 m section of creek in February 2012 failed to find any crayfish at all, where once they were both plentiful. This was so unusual that we repeated the survey in March 2012 but again we only found macro invertebrates at the survey site. Further surveys of the surrounding area investigated five feeder streams into Calverts creek; one site produced no crayfish and the other 4 streams contained only *C. destructor* in residence (McCormack 2012a). Qualitative evidence would suggest that it has displaced the native *Euastacus australasiensis*.

Since that time *C. destructor* have spread throughout the Mooney Mooney Creek catchment and continue to spread rapidly (McCormack 2012a).

Example 3 - Mooney Mooney Creek, Hawkesbury River catchment (dispersal)

Little Mooney Mooney Creek (site – 52) was originally surveyed on the 1st December 2010. The creek was surveyed at the road bridge both upstream and downstream, and at that time the main creek contained *Euastacus spinifer* with *Euastacus australasiensis* found within adjacent, smaller, tributaries. The same site was surveyed again in February 2012. At this time, the main creek still contained relatively good numbers of *E. spinifer* upstream but *E. spinifer* was absent downstream with only *C. destructor* present in large numbers. *Euastacus spinifer* has seemingly been replaced by *C. destructor* downstream of a road crossing.

A total of 37 sites representative of the whole Mooney Mooney Creek catchment were surveyed in 2011 - 2012, *C. destructor* was found at 9 sites many in very high numbers; over 30/box trap/2 hours (McCormack 2012a).

Example 4 - Mount Royal National Park, Hunter River catchment. (harassment)

Tributary of Fal Brook Creek (site – 28) at 598 m above Lake St Clair, a recreational fishing area. Endemic *Euastacus reductus* was captured (5 g, 22.92 mm OCL) under the same rock with two invasive *C. destructor* (2 g and 19 g). The *E. reductus* had no chelae and a cracked carapace indicative of aggressive interaction with other crayfish. *Euastacus reductus* is a typical *Euastacus* dwarf group crayfish. They are a small, slow growing species, being excellent burrowers, preferring marginal areas to avoid the other *Euastacus* species that occur in the same streams

(McCormack 2012). All *Euastacus* species exhibit the fight or flight response to a threat. *Euastacus* species are all relatively aggressive and will fight each other if they are of a similar size. Death from fighting is rare among *Euastacus* species; generally one will stand down and withdraw, recognising the dominance of the larger, stronger animal (McCormack 2012). Creation of a dominance hierarchy within a population of animals typically involves a period of agonistic activity in which winning and losing decide relative positions in the hierarchy (Herberholz *et al*. 2001). The fighting decreases when one animal (the subordinate) breaks off contact with its opponent (the dominant) and avoids physical contact by escaping or retreating (Issa *et al*. 1999). Most fighting is claw to claw and minor injury to claws is common in *Euastacus*. It is not uncommon for a crayfish to lose a single claw in fighting. Loss of both claws is not something that normally occurs in *E. reductus* or any *Euastacus* populations.

Further research is required to determine if the behavioural response displayed by *C. destructor* to endemic eastern *Euastacus* species is a normal consequence of aggression and dominance or an abnormal response creating an additional threatening process.

Example 5 - Barrengarry and Dharawal Creeks, Shoalhaven catchment (possible pathogen transmission)

The potential introduction and spread of disease by exotic species was first raised by (Holdich 1988; Horwitz 1990). An insidious threat generated by *C. destructor* is the possible introduction and proliferation of thelohania that is common in most *C. destructor* populations throughout Australia (McCormack 2013). Thelohania is a microscopic, microsporidian parasite that is visually identifiable; it is a single-celled parasite that spreads its infection by spores that increase in numbers in the abdominal muscle until the muscle turns from clear to white (a porcelain colour).

Morgan and Beatty (2005) found a wild population of yabbie *C. destructor* in the Hutt River, Western Australia to have the serious porcelain disease caused by the microsporidian *Thelohania parastaci*. They stated the disease is contracted by a crayfish consuming infected tissue and that it is possible that the endemic crayfish may be able to contract this disease by consuming infected yabbie tissue. Therefore, the potential accompanying spread of this and other diseases by yabbie introductions is of considerable concern in that region and possibly for our endemic eastern crayfish species.

In April 2011 both *Euastacus hirsutus* and *C. destructor* were captured together in Barrengarry Creek (site – 37). A total of nine *E. hirsutus* and six *C. destructor* were captured. One of the *Euastacus* crayfish was infected with thelohania.

In November 2011 a survey of Dharawal Creek found both endemic *E. hirsutus* and *C. destructor* together in the creek (site – 50). A total of 30 crayfish were captured in our survey, 11 *E. hirsutus* and 19 *C. destructor*. Of the 30 crayfish only one, *E. hirsutus* displayed signs of thelohania infection. These are the only ACP records of thelohania in *Euastacus* crayfish (in thousands of ACP records), we speculate that the invasive *C. destructor* may be responsible for the pathogen transmission to *E. hirsutus*.

Example 6 - Wildes Meadow Creek, Shoalhaven Drainage, Southern Highlands (competition)

Euastacus dharawalus is a member of the giant spiny crayfish group with an extremely restricted distribution only occurring in Wildes Meadow Creek above Fitzroy Falls (McCormack 2013). *Cherax destructor* was first recorded in this creek by McCormack (2006) site – 15. *Euastacus dharawalus* displays spination on the chelae, cephalothorax and abdomen and attains an OCL of 86 mm and weight of 300 grams (McCormack 2008). It can easily be identified from the invasive *Cherax* crayfish found in the same streams by the presence of lateral propodal spines along the base of the chelae; *Cherax* have a smooth lateral propodal edge and generally smooth with no spination of cephalothorax or pleon (McCormack 2013).

Cherax destructor can attain a size of 81 mm OCL and weigh 350 grams (McCormack 2008), so both species can attain a similar size and compete for the same food sources. The difference is the rapid growth of *C. destructor* reaching sexual maturity in six months whilst the *E. dharawalus* takes 5 - 7 years (McCormack 2012). Additionally, the *Cherax* crayfish have multiple breedings per year whilst the *Euastacus* only have one. Freshwater crayfish are most vulnerable when small, the fast growth of *Cherax* sees them moving through this vulnerable stage in several months, whilst the slow growth of *Euastacus* makes them extremely vulnerable for several years. The aggressive interactions between *E. dharawalus* and *C. destructor* in Wides Meadow Creek was first recorded by Coughran *et al*. (2009).

Cherax destructor is a highly sort recreational fishing species and the huge crayfish resource created by the proliferation of *C. destructor* throughout the reservoir and associated creeks, generates an attractive resource for target by recreational fishers. Our surveys in the creek below the reservoir using standard recreational fishing methods over a one hour duration captured over 5 kgs of crayfish. Only three *E. dharawalus* for a total weight of 143 grams were captured. At the same time, at the same site, 73 *C. destructor* were captured for a total weight of 5 kg. The native endemic crayfish *E. dharawalus* was outnumbered 24:1 by *C. destructor*. Both species are probably competing for the same resources, Coughran *et al*.(2009) first suggested that translocated *Cherax* species may easily out compete and rapidly displace this endemic *Euastacus* crayfish.

Euastacus dharawalus (Morgan 1997) was listed in November 2011 as a "Critically Endangered Species" by the NSW Fisheries Scientific Committee, making it the first *Euastacus* species in Australia to be listed as Critically Endangered under any State or Federal Government conservation legislation.

Example 7 – The potential to alter the gene pool of endemic Cherax species (genetic pollution)

The dangers of genetic pollution by invasive *C. destructor* to endemic eastern *Cherax setosus* was first suggested by McCormack and Coughran (2011). *Cherax setosus* may be susceptible to reproductive interference from *C. destructor*. Cross-breeding experiments between C.

setosus and various strains of *C. destructor* have resulted in sterile, allmale hybrid off-spring (Lawrence *et al.* 1998, 2000) and the establishment of *C. destructor* within the distribution of *C. setosus* is therefore of considerable concern (McCormack and Coughran 2011).

Cherax cuspidatus, *Cherax leckii* and *Cherax setosus* are endemic to eastern drainages of NSW and invasive *C. destructor* now occurs within their catchments. The potential of interbreeding to alter the genetic pool of each species must be considered a major potential threat.

Summary and recommendations

Unlike the endemic freshwater crayfish species, *C. destructor* grows fast, matures early, breeds frequently and has a shorter gestation period. These are traits that equip it to potentially out-compete the endemic freshwater crayfish. Their rapid proliferation, aggressive disposition and invasive habits tend to rapidly displace the endemic eastern crayfish. The NSW Fisheries Scientific Committee has listed 'The introduction of fish to fresh waters within a river catchment outside their natural range' as a Key Threatening Process (KTP) under the Fisheries Management Act 1994 (FM Act). The yabby, *C. destructor* is included in the definition of 'fish' under the FM Act and hence the impact on native freshwater crayfish would be covered by the existing KTP. (Leishman pers. comm. 2012: Gilligan pers. comm. 2012).

Much damage has been done in the past and most infestations of exotic species once established in an aquatic ecosystem is often viewed as permanent, with eradication difficult or almost impossible (Horwitz 1990; Lodge *et al.* 1998; Beatty and Morgan 2013). The effort now should be towards remediation, prevention and management. Many of the infestations are occurring because the stream conditions now favour *C. destructor* and not the endemic species. Drought and changes to stream flows are significant threats to eastern crayfish species. Most need regular water to survive and prefer flowing stream conditions, over extraction or obstructions to flows by dams or weirs could also have serious negative impacts on endemic freshwater crayfish but favour the invasive crayfish that prefer still static pools and impoundments.

Wherever outbreaks of *C. destructor* occur in eastern drainages the future of endemic crayfish in that area is seriously threatened. Unexplainably, several times we have found *C. destructor* and *Euastacus* crayfish together in good numbers at a site. Yet follow up surveys several years later of the same site failed to capture any crayfish or only very low population numbers. This reversal of population numbers of both species remains unexplained and of concern. Understanding this phenomenon would be greatly assisted by further research and may provide a key to unlocking the knowledge to control this invasive species.

Erosion of hillslopes and stream banks has greatly increased in historical times, supplying vast quantities of sediment to rivers, much of which is still stored within the river system. The stored sediment will continue to effect in-stream and estuarine ecosystems for many decades. In most Australian catchments the dominant source of sediment is stream bank erosion. (Posser *et al.* 2001). Additional sediment carried by runoff from urban developments, road construction, forestry practices and agricultural practices is all a concern, as sediment can fill the deeper waterholes that are utilized by many *Euastacus* species as refuges during drought or low stream flows. Many species are threatened by sedimentation, as sediment can fill the holes destroying their safe refuges (Brierley and Fryirs 2005; McCormack 2012). *Cherax destructor* is a strongly burrowing species that occurs abundantly in ephemeral floodplain habitats (Austin *et al.* 2003), they are naturally most abundant in dryland waterways of the interior, especially the floodplain wetlands subjected to intermittent cycles of drying and filling (Rankin 2000). In eastern drainages stream beds without deeper holes favour this species.

Intact riparian zones composed of native vegetation are essential to most of our native eastern species for a range of functions. Riparian vegetation provides many important ecological benefits: a source of organic matter such as leaves, twigs and branches; a supply of large woody debris for aquatic ecosystems; habitat and spawning sites for many native fish species; may act to lower the water table and help reduce the flow of salt into streams; provides shade and shelter, buffers temperature; stabilises river beds and banks, binds soil and protects against stream bank erosion and slumping; acts as a filter for sediments, phosphorous and organic nitrogen; improving the quality of water entering watercourses (HCRW 2013). Restoration of cleared stream banks should be a priority with the re-establishment of native vegetation along the banks (Clemens pers. comm. 2012).

Lack of education is the greatest threat to our native species. Most of the infestations of *C. destructor* occur deliberately by people due to ignorance. Most are unaware of the consequences of releasing *C. destructor* into the environment, with little knowledge of the endemic species present or the possibility of any negative impacts upon them. Better education of the general population would do much to reduce further outbreaks of invasive *Cherax* and should be a priority. It is recommended that a brochure on the dangers of releasing *C. destructor* to the wild be developed and actively distributed by local and state agencies. Additionally, it should be mandatory that anyone selling live *C. destructor* in NSW issue the brochure at time of sale, be that an aquarium or pet shop selling a single yabby as an aquarium pet, a commercial yabby farm selling stock, or a local bait and tackle shop selling live yabbies for bait.

It is recommended that research continues to document the spread of *C. destructor* into eastern drainages, with ongoing research needed into the scale of impacts associated with their proliferation.

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